PARTS OF THE ORIGINAL DOCUMENT

ARE OF POOR REPRODUCTIVE QUALITY

CERTAINES PARTIES DU DOCUMENT ORIGINAL

SONT DE PIÈTRE QUALITÉ DE REPRODUCTION

FIELD EVALUATION
OF
RESIDENTIAL VENTILATION SYSTEMS GUIDELINES

FINAL REPORT

PREPARED FOR:
THE POLICY DEVELOPMENT AND RESEARCH SECTOR
OF
CANADA MORTGAGE AND HOUSING CORPORATION

PREPARED BY:
BALANCED ENERGY SYSTEMS TECHNOLOGY INC.

SEPTEMBER 1985

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

ABSTRACT

This report documents the results of a Field Evaluation of Draft Guidelines for the Design and Installation of Residential Controlled Ventilation Systems. Eight builders were selected and asked to review the draft guidelines. After reviewing them, the builders were expected to design and install ventilation systems in accordance with their requirements. Field testing of the houses, after construction, revealed that, in almost all cases, the installed ventilation system did not operate in accordance with the requirements of the guidelines. The primary reasons for this appear to be the lack of clarity in the guidelines themselves; insufficient knowledge and experience in the design of residential ventilation on the part of the builders and heating contractors; and the unavailability of suitable equipment and systems.

Keywords: Ventilation, Controlled Ventilation, Heat Recovery, Residential HVAC Systems, Forced Ventilation, Mechanical Ventilation.

This study was conducted by Balanced Energy Systems Technology Inc. for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretations, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

TABLE OF CONTENTS

List of Tables
Summary

1.0 Introduction 1

2.0 Review of Ventilation Guidelines 4

3.0 Field Testing Procedures 6
3.1 Airtightness Tests 7
3.2 Ventilation System Air Flows 7
3.3 Distribution Systems Air Flows 8
3.4 Discussion of Field Testing Procedures 9

4.0 Field Test Results 13
4.1 House ON1 - Test Results 13
4.2 House ON2 - Test Results 18
4.3 House ON3 - Test Results 23
4.4 House ON4 - Test Results 27
4.5 House ON5 - Test Results 31
4.6 House BC1 - Test Results 35
4.7 House BC2 - Test Results 40
4.8 House BC3 - Test Results 45
4.9 Comparison of Field Test Results 50

5.0 Homeowners Questionaire 58

6.0 Conclusions 61

LIST OF TABLES

TABLE		Page
3.1	House Specifications	11
3.2	Air Flow Balance Sheet	12
4.1	Air Flow Balance - ON1	16
4.2	Air Flow Balance - ON2	21
4.3	Air Flow Balance - ON3	25
4.4	Air Flow Balance - ON4	29
4.5	Air Flow Balance - ON5	33
4.6	Air Flow Balance - BC1	37
4.7	Air Flow Balance - BC2	43
4.8	Air Flow Balance - BC3	48
4.9	Ventilation System Flow Measurements	52
4.10	Air Circulating System Flow Measurements	55
4.11	Frequency Distribution	57
5.1	Results of Homeowner Survey	60

LIST OF FIGURES

	Page
4.1 Air Flow Balance ON1	17
4.2 Air Flow Balance ON2	22
4.3 Air Flow Balance ON3	26
4.4 Air Flow Balance ON4	30
4.5 Air Flow Balance ON5	34
4.6.1 Chimney Backdraft Test BC1	38
4.6.2 Air Flow Balance BC1	39
4.7.1 Chimney Backdraft Test BC2	42
4.7.2 Air Flow Balance BC2	44
4.8.1 Chimney Backdraft Test BC3	47
4.8.2 Air Flow Balance BC3	49
4.9 Total Air Flow Delivered to each room	56

LIST OF APPENDICES

(These are separately bound)

A1. Comments on Guidelines by Builders

A2. Draft of Guidelines

A3. Air Flow Test Procedure & Calibration of Equipment

A4. Alternative Air Flow Measuring Procedure

A5. Comparison of Tracer Gas Tests

A6. Determination of the proportion of outside air exiting from air outlets.

A7. Design data & test results

The study was conducted by Balanced Energy Systems Technology Inc. It was divided into three basic segments. The first was a review of the draft guidelines by eight builders selected across Canada. These builders provided their initial comments of these proposed guidelines. This was followed by the second phase, the design and installation of ventilation systems, in accordance with these guidelines, in houses currently being constructed by these builders. Upon installation of the systems, preliminary field testing of their operation was conducted as part of the third phase of the study.

The results of this field evaluation of the draft Guidelines for the Design and Installation of Residential Controlled Ventilation Systems revealed several problem areas. Although the awareness of the participating builders was high concerning the need for ventilation, the knowledge and understanding related to the design, installation and operation of these systems was inadequate. In addition, the heating and ventilating contractors employed by the builders were reluctant to abandon traditional design and construction practices, and unwilling, or unable, to comprehend the concepts presented in the guidelines. This, combined with the unavailability of suitable heating and ventilating equipment in some instances, resulted in the construction of houses which do not meet the ventilation requirements of the guidelines.

At the time of this study, there were no comprehensive design manuals, similiar to the HRAI's Residential System Design Manual, which were geared directly to energy efficient and airtight housing. The contractors were unable to size ductwork, heating equipment and fans required for a properly operating ventilating system, without a great deal of assistance from the study team. Some of these problems should be alleviated in the future with the HRAI's recent publication of the "Installers' Manual for Heat Recovery Ventilators", and associated courses.

The guidelines were also not very specific in describing which types of heating systems were acceptable and cost effective. The whole

EXECUTIVE SUMMARY

In 1982, the Canadian House Builders Association (CHBA), formerly the Housing and Urban Development Association of Canada (HUDAC), commissioned and directed the IBI Group, Toronto, to prepare a set of guidelines for builders to assist them in the design and installation of residential controlled ventilation systems. The basic principles around which the guidelines were focused, are fundamental to the residential ventilation issue. Specificially, controlled ventilation is required as a means of supplying fresh outside air to maintain adequate indoor air quality, and remove excessive moisture. The guidelines use ASHRAE Standard 62-1981, which recommends 5 litres per second of outdoor air be supplied to each habitable room, as a basic design criteria. This flow rate is expected to dilute and remove pollutants which can be harmful to occupant health. Also, in order to control excess humidity, the guidelines recommend increased exhaust rates, when required, from rooms such as the kitchen, bathroom, and washrooms.

In 1984, the field evaluation of these guidelines was initiated by the CHBA Task Force on Airtightness, Controlled Ventilation and Heat Recovery, with funding and project management by the Research Division of CMHC. The primary objectives of this study were:

Provide an inital assessment of the difficulties encountered by builders and subtrades concerning the implementation of the Guidelines.

Develop instrumentation and methodologies for measuring and monitoring the performance of ventilation systems, and analyzing the results.

Provide a preliminary assessment of the performance and safety of the ventilation systems recommended in the guidelines.

issue of combustion appliances in airtight homes requires closer scrutiny, because of the potential health threat if these devices malfunction. Both the builders, and the heating contractors, have to be provided with documents which clearly define the various heating system configurations deemed acceptable for use in controlled ventilation houses. To some extent, this will be hampered by the lack of commercially available and cost effective equipment suitable for these systems.

Another problem was the actual performance of the equipment and systems, once installed. In almost all cases, ventilating equipment and systems did not supply the volume of air that was specified. In some cases, this may be due to ducting design; in others, it is equipment performance, or differences between as designed, and as installed.

1.0 INTRODUCTION

The push to build energy efficient houses was ignited by the world oil crisis in 1973. Since that time, there have been a number of government sponsored programs promoting improved energy efficiency in new and existing houses. The major thrust of this activity has been to reduce heat loss by increasing insulation values, and reducing air infiltration rates. The result is more energy efficient airtight housing.

Recently, there has been growing concern about the quality of the "lived-in" environment in such airtight houses. Adequate fresh air must be supplied to ensure the health and safety of the occupants, since many new energy efficient houses operate with natural infiltration rates less than 0.1 ACPH. A second consideration is the need for an adequate air supply to combustion devices such as furnaces, water heaters, stoves and fireplaces. If the air supply is insufficient, backdraft conditions can exist in chimneys and flues which can result in potentially hazardous situations.

To satisfy these demands for fresh air, ventilation systems have been incorporated in the design and construction of many new airtight houses. These systems range from passive vents, to elaborate heat recovery systems. However, there is considerable uncertainty as to what constitutes adequate air supply for new housing, and to what extent the available commercial systems can reliably meet these needs.

Most of the problems which have been experienced to date, stem from the fact that little is known about the dynamics of air movement within a house, with respect to the competition for air supply by combustion devices, ventilating equipment and the occupants themselves.

To provide guidance on the understanding of ventilation in new housing, the Canadian Home Builders Association (CHBA), formerly the Housing and Urban Development Association of Canada (HUDAC), commissioned and directed the IBI Group, Toronto, to prepare a set of guidelines for builders. The purpose of the guidelines was to assist in the design and installation of residential controlled ventilation systems. Through increased awareness and understanding of ventilation concerns, builders would be able to construct new energy efficient homes which would provide safe and economical comfort for their occupants.

The field evaluation of these quidelines was initiated by the CHBA Task Force on Airtightness, Controlled Ventilation and Heat Recovery, with funding and project management by the Research Division of CMHC. The primary objectives of this study were to:

Provide an inital assessment of the difficulties encountered by builders and subtrades concerning the implementation of the Guidelines.

Develop instrumentation and methodologies for measuring and monitoring the performance of ventilation systems, and analyzing the results.

Provide a preliminary assessment of the performance and safety of the ventilation systems recommended in the guidelines.

The study was divided into three basic segments. The first was a review of the draft guidelines by eight builders selected across Canada. These builders provided their initial comments of these guidelines. This was followed by the second phase, the design and

installation of ventilation systems, in accordance with the guidelines, in houses currently being constructed by these builders. Upon installation of the systems, preliminary field testing of their operation was conducted as part of the third phase of the study.

This final report presents the findings of this study.

2.0 REVIEW OF GUIDELINES

Nineteen builders were contacted, and asked to participate in the Ventilation Guidelines project. A selection of eight, three in British Columbia designated as BC1-3, and five in Ontario designated as ON1-5, was made.

All builders were asked to review the guidelines, and make comments regarding its format and content. Most builders found the guidelines complex and not readily understandable. The most commonly asked question after reading the guidelines was, "Where does it tell us how to select and size the equipment for our houses?".

The builders also expressed concerns about the added cost of designing and installing these systems, especially with regard to:

- separate furnance rooms
- mechanical dampers
- interlocking relays and valve controls

To complicate this matter further, some of the equipment proposed in the guidelines was not readily available and/or there was little operating experience. The available, smaller capacity furnaces lacked the blower capacity to provide the minimum air movement in large energy efficient houses. This also held true for heat exchangers.

Comfort and acceptibility of the systems was another area of concern. Specifically, the risk of siphoning cold air into the heating ducts, thereby creating cold air drafts in the living space, was of concern. Also, the introduction of these complex systems would put an additional burden on the consumer to understand, operate and maintain these systems.

The guidelines assume "airtight" construction. The sizing of ventilation components, based on this assumption, results in oversizing of the system. This, in turn, results in higher than necessary infiltration rates, and higher than necessary heat loss. One builder in particular, requested and received permission to deviate from the guidelines, based on this observation.

As defined in the guidelines, no consideration is given to any unfinished basement area in the design of the ventilation system. The builders felt that it should be assumed that any unfinished basement would eventually be finished; and the ventilation system be sized accordingly.

For specific builder comments on the proposed guidelines, see Appendix "A", Guidelines Commentary.

3.0 FIELD TESTING PROCEDURES

The eight builders, selected to participate in the study, were asked to submit blueprints showing the layout and sizing of ducts, specifications of heating and ventilating equipment, and any design calculations used to prepare these designs. Table 3.1 shows a summary of the basic design specifications for each house. The members of the study team were to act on an advisory basis only, to assist the builders in designing the systems only when requested. A number of calculations were done for the purpose of checking the designs submitted by the builders. The first calculation was to ensure that the capacity of this ventilation system ie. heat recovery ventilator, exhaust fan, and supply fan met the minimum requirements suggested in the proposed ventilation guidelines. The ventilation guidelines specify a minimum 5 L/s per habitable room. In almost all cases, the means of distributing this outside air was through a central air circulating system which was usually an integral part of the heating system. For this reason, the HRAI Manual J was used to calculate the appropriate size of the heating system; and the HRAI Residential System Design Manual was used to calculate appropriate air flows and duct sizing. At the time the study was conducted, there were no manuals, such as the recent HRAI publication, "Installors Manual for Heat Recovery Ventilators", which could be used to assist the builders. The numbers generated using the HRAI manuals and the proposed ventilation guidelines were used as a reference against which to measure the actual performance of the installed systems.

The main purpose of the field testing was to determine whether the predicted performance of the ventilation systems, designed and installed in each of the test houses, was being achieved. To accomplish this, the following tests were conducted at each house:

*airtightness tests,

*ventilation system air flows, and

*distribution system air flows.

The following sections discuss these procedures.

3.1 Airtightness Tests

The purpose of the airtightness testing was to determine the degree to which the study houses had achieved an airtight envelope. Since the ventilation guidelines assume complete airtightness, and hence allow no consideration for natural infiltration, this test was important in order to consider the relevancy of this assumption in analysing the results. The test was conducted in accordance with CGSB Standard 149-GP-10M. In Ontario, this test procedure was used to measure the airtightness of the houses under several conditions:

1. Intakes and exhausts of ventilation system unsealed and ventilation system off.

2. Intakes and exhausts of ventilation system sealed and ventilation system off.

3. Intakes and exhausts of ventilation system unsealed and ventilation system and running on low speed.

4. Intakes and exhausts of ventilation system unsealed and ventilation system running on high speed.

In British Columbia, the CGSB test was used to measure the airtightness of the house. Then, the door fan was used to measure the points at which spillage and back drafting occur on various appliances within the house.

3.2 Ventilation System Air Flows

Ventilation, as defined by the proposed "Guidelines", is the process of removing and supplying air by natural or mechanical means from and to any indoor space. "Controlled Ventilation"

is defined as systems which mechanically supply fresh outside air and exhaust inside air to maintain adequate indoor air quality, and to remove excessive moisture. In addition, controlled ventilation includes systems which mechanically supply air for combustion devices or air extraction devices.

Since the proposed guidelines assumed no natural infiltration in the sizing of controlled ventilation systems, the purpose of this test was to measure the air flows associated directly with the operation of the mechanical ventilation system. Air flow measurements were taken using a velometer in junction with a nozzle/diffuser which is described in Appendix 'B'. The nozzle/diffuser was placed over air inlets and outlets which were part of the mechanical ventilation system of the house. Air flow measurements were made in a straight portion of the nozzle/diffuser using a velometer. Air flows were measured with the ventilation system running on high and low speed. Based on the measured air flows and calibration factors determined for the nozzle/diffuser, the volumes of the air being moved could be calculated

3.3 Distribution System Air Flows

In all cases in this study, a separate mechanical system was used to distribute fresh air throughout the house, as well as circulate existing air. In almost all cases, this distribution/circulation system was part of a central forced air heating system. Measurements of air flow supplied to each room by the distribution system, were determined using the technique discussed in 3.2.

In most of the installations, fresh air supplied by the ventilation system was ducted into the return air plenum, or ducted close to a return air grille. If one assumes perfect mixing of air flows under these conditions, the ratio of fresh air to recirculated air

is the same at each supply outlet, and is equal to the ratio of total fresh air supply to total recirculated air. This assumption was used to determine the actual amount of fresh air being supplied to each room by the distribution system.

3.4 Discussion of Field Testing Procedures

There are several factors which affect the validity of results which can be extracted from the measurements made using the test procedures discussed here. Limitations on the time available to conduct field tests, as well as, limitations on the scope of the study, made it impossible to follow-up on the initial findings with improved test procedures. The four major areas for concern in interpreting the results of these field tests are:

i) inability to identify where system duct leakage may be causing erroneous results,

ii) the degree of mixing between outside air supplied by the ventilation system, and air recirculated by the distribution system,

iii) the degree of mixing between outside air and recirculated air, when the ventilation system is not connected directly to the distribution system, and

iv) the degree of unintentional infiltration of air.

More comprehensive testing would be required to eliminate these unknowns. Total air flow measurements should be taken at the main supply and return air plenums to determine the total amount of circulated air. Upon measuring and summing the air flow through each supply grille, an estimate of duct leakage can be made. If there is a significant temperature difference between outside air and recirculated air, it may be possible to determine the degree of mixing by measuring air

temperatures in the ductwork. This analysis becomes slightly more difficult when the fresh air supply is not connected directly to the return air plenum. Tracer gas testing can be used to determine natural infiltration rates. Tracer gas techniques could possibly be used to determine the degree of fresh air distribution, if the tracer gas is introduced at the fresh air inlet. Some tracer gas tests were conducted on house ON1. The results of this testing are presented in Appendix B.

The objective of the field testing discussed here, is to produce a complete air flow balance for the house. The measurements taken should be sufficient to complete an air flow balance sheet similiar to that presented in Table 3.2. In the following sections, attempts have been made to complete this air flow balance sheet, based on the limited testing which was completed. Although these results are highly questionable, in view of the limitations of the test procedures, they provide some insight into the problems associated with designing, installing and operating suitable ventilation systems.

TABLE 3.1
HOUSE SPECIFICATIONS

HOUSE NO.	LOCATION	DEG. DAYS	STYLE	AREA M^2	1st HEATING SYSTEM	FUEL	2nd HEATING SYSTEM	FUEL	DHW
ON1	FREELTON	4220	BUNGALOW	128	FORCED AIR	ELEC.	NONE	NONE	ELEC.
ON2	OTTAWA	4500	2-STOREY	158	FORCED AIR	GAS	F. P.	WOOD	ELEC.
ON3	TORONTO	4200	2-STOREY	248	FORCED AIR	ELEC.	F. P.	WOOD	ELEC.
ON4	SUDBURY	5400	SIDE-SPLIT	112	BASE BOARD	ELEC.	F. P.	WOOD	ELEC.
ON5	MARATHON	5500	SIDE-SPLIT	125	FORCED AIR	ELEC.	NONE	NONE	ELEC.
BC1	PR. GEORGE	5300	BACK-SPLIT	175	FORCED AIR	GAS	W. S.	WOOD	GAS
BC2	LANGELY	3500	2-STOREY	167	FORCED AIR	GAS	F.P.+ W.S.	GAS+WOOD	GAS
BC3	RICHMOND	3033	2-STOREY	126	FORCED AIR	GAS	F. P.	WOOD	GAS

Table 3.2

AIR FLOW BALANCE SHEET

AIR CIRCULATION SYSTEM

	Calculation	Measured
Supply Grilles		
1 Bedroom 1		
2 Bathroom 1		
3 Bedroom 2		
4 Den		
5 Living Room		
6 Front Entrance		
7 Dining Room		
8 Kitchen		
9 Bathroom 2		
10 Laundry		
11 Back Hall		
12 Duct Leakage	_____	_____
Total Supply		
Return Grilles		
R1 Return		
R2 Return		
Duct Leakage	_____	_____
Total Return		
Total Circulated Air	═══	═══

VENTILATION SYSTEM

Exhaust		
Intake		
Net Infiltration/Exfiltration	_____	_____
Total Fresh Air	═══	═══

4.0 FIELD TEST RESULTS

Field tests on each of the study houses were conducted during the spring and summer of 1984. The following sections discuss the designs and field testing results for each house. Complete information on each house is presented in Appendix "C" Design Data and Test Results.

4.1 House ON1 - Test Results

ON1 is a single story bungalow with a central, forced air, electric furnace. It also has a central, heat recovery ventilation (HRV) system which is capable of exchanging 104 L/s at its highest speed. The HRV "dumps" the preheated fresh air into the laundry room area. This fresh air is circulated throughout the house via a return air grille to the furnace. The high speed operation of the heat exchanger is controlled by dehumidistats in the bathrooms and kitchen. Low speed operation can be set manually.

The major question, in the design of this ventilation system, is the dumping of cold outside air into the laundry room area. Although there is a central forced air system, which should circulate this fresh air to all parts of the house, the question of comfort, at the point where the fresh air is introduced into the living space, arises.

An alternative way of introducing the air into the living space, would be to duct the air directly into the return plenum, thus tempering cold fresh air with warm recirculated air before distributing it throughout the house.

Our concerns with the design were expressed to the heating contractor prior to construction. However, the original design was maintained, partly due to the persistence of the contractor,

and partly to our curiosity to see the system in operation. There would be little difficulty in connecting the fresh air supply to the cold air return, if the cold air created any discomfort during the winter.

4.1.1 Airtightness Tests - ON1

The airtightness tests on this house revealed equivalent leakage area of 0.022 m^2 at 10 Pa, and an air change rate of 1.8 acph at 50 Pa; with the HRV system unsealed and not running. The ELA was reduced to 0.013M^2 at 10 Pa when the inlet and exhaust vents were sealed. The air change rate at 50 Pa also dropped to 1.12 acph. The airtightness results, with the HRV system running at low and high speed, were virtually the same as the sealed case. Smoke pencil inspections revealed very few detectable leaks.

4.1.2 Ventilation System Air Flows - ON1

Table 4.1 presents a comparison of the air flows which were expected, due to various calculations done before field testing, with the air flows actually measured. From this table, based on the number of habitable rooms, the ventilation system requires a minimum continuous air flow of 40 L/s. This is the minimum required ventilation rate suggested in the proposed guidelines. The actual exhaust rate was found to be 34 L/s, and the actual fresh air intake rate was measured at 23 L/s. The balance of fresh air was assumed to be leaking into the house through unknown avenues. Therefore, the HRV system is supplying about 85% of the minimum required air flow, when operating on low speed. When operating on high speed, the HRV system exhausted only 40 L/s. Design specifications for the equipment indicated a capacity of 104 L/s.

4.1.3 Distribution System Air Flows

Table 4.1 also shows predicted and measured values for air distribution to each room in the house. The total air distributed to each room is based on HRAI, Residential System Design Calculations. Assuming perfect mixing of the air supplied by the HRV system and the recirculated air, the amount of fresh air distributed to each room is calculated. The remaining air flow is considered to be recirculated air. These calculations show that only two rooms, the living room and front entrance, will theoretically receive the minimum required continous air flow. In actuality, based on measured air flows, none of the rooms receive the minimum air flow required by the guidelines. Also, due to the nature of the air distribution system, areas which do not require fresh air such as hallways, entrances, and laundry rooms are, in fact, receiving fresh air. Since the fresh air is dumped into the laundry area and is not ducted directly into a return air plenum, the degree to which mixing is achieved, is unknown.

Figure 4.1 shows, schematically, the balance of air flows within the house.

TABLE 4-1
AIR FLOW BALANCE
HOUSE NO. [illegible]

AIR DISTRIBUTION SYSTEM

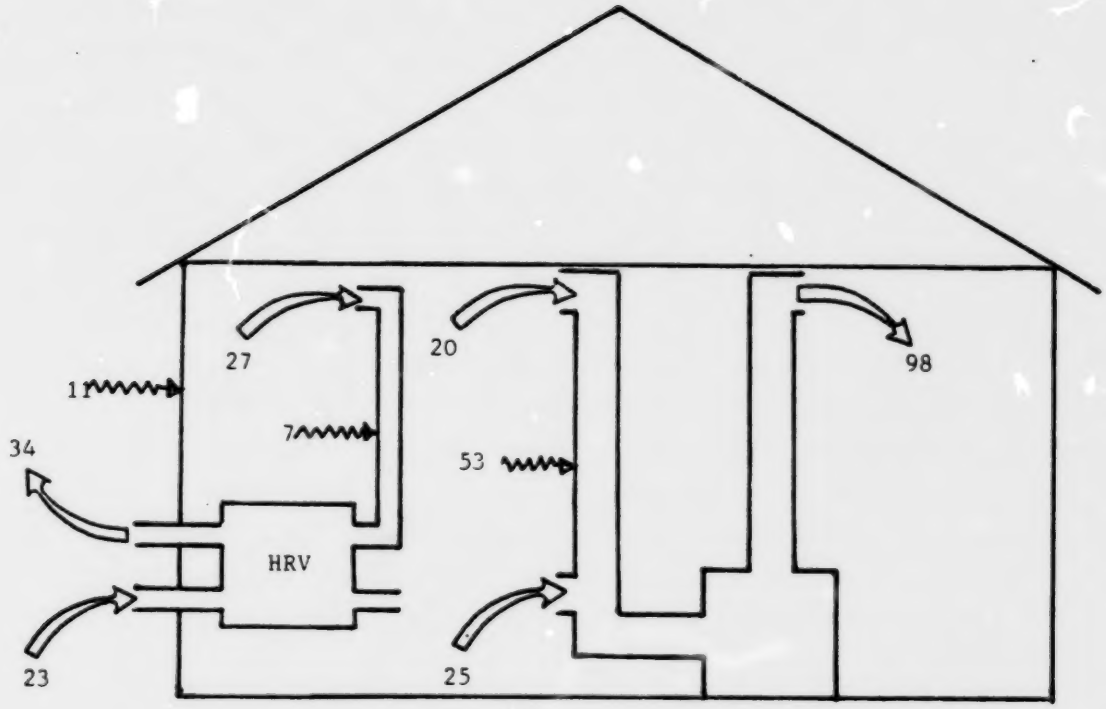
Level or	Outdoor Air for ventilation	Calculated Outside Air			Measured Total	Derived Return	Outside Air
		Per Room	Outside Air	Total			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Supply Outlets							
1 Bedroom 1	5	15	-	15	11	7	3
2 Bedroom 2	5	15	7	22	17	5	3
3 Bedroom 3	5	15	-	15	12	7	3
4 Den	5	15	-	15	11	4	3
5 Living Room	5	15	5	20	9	6	3
6 Dropped Entrance	-	15	5	20	8	4	3
7 Dining Room	5	15	-	15	7	4	3
8 Kitchen	5	15	-	15	8	5	3
9 Bathroom 2	5	-	-	5	12	7	3
10 Laundry	-	5	5	10	8	5	3
11 Boat Hall	-	5	5	10	12	9	3
12 Duct Leakage [1]	-	-	-	-	-	-	-
Total Supply	40	135	40	175	95	64	31
Return Outlets							
01 Return				85	41		
02 Return				90	54		
Duct Leakage [1]					57		
Total Return				175	95		
VENTILATION RATES							
Exhaust				40	31		
Intake				40	20		
House Leakage [1]					11		
Total Outside Air				40	31		

Notes:
1. The Ventilation Guidelines require 5 L/s per habitable room.
2. Recirculated air is total flow less fresh air.
3. Check sum: Total Fresh Air/Total Supply=Total Outside/Total Room Supply.
4. Total room supply calculated using ASHRAE RCF Manual.
5. Measured air flows
6. Difference between 4 & 5
7. Outside air per room is based on total outside air pro-rated to each room in proportion to total measured air
8. Difference between sum of measured return flows & sum of measured total.
9. Difference between intake and exhaust.
10. Total outside air is based on greater of measured exhaust or intake.
11. Duct and House leakage account for differences between supply and return or exhaust and intake measurements.

FIGURE 4.1

AIR FLOW BALANCE

HOUSE ID: ON 1



All Flows in L/s

4.2 House ON2 - Test Results

ON2 is a two storey house with a central forced air, high efficiency, condensing gas furnace. The ventilation system is, primarily, a centralized exhaust fan which draws air continuously from the bathrooms and kitchen. The fan has a rated (or nominal) air flow capacity of 125 L/s. Higher exhaust rates are provided by additional exhaust fans in the bathrooms and kitchen, capable of moving up to 25 L/s each. These smaller fans act as boosters to the central exhaust fan. The primary source of fresh air is a passive vent, about four inches in diameter, in the basement, next to the furnace. This vent is intended to supply both combustion air, when required, as well as ventilation air. The condensing gas furnace is equipped with an induced draft fan and proving switches, to ensure that backdrafting is not a problem. In addition, there are passive vents to, each of, two fireplaces in the house. Air distribution is provided by the forced air system of the furnace.

The ventilation system in this house does not conform with the requirements of the ventilation guidelines. The primary deviation is, that, there is no controlled means of supplying fresh air throughout the house. The decision, not to include a controlled supply of fresh air, was a conscious one, on the part of the builder. It was based on an objection to one of the fundamental assumptions in the proposed guidelines. That is, the assumption of a completely airtight envelope and no allowance for natural infiltration. The houses being constructed by the builder, were expected to be more "airtight" than conventional houses, but, were not expected to meet such stringent requirements, as specified by the R2000 Program. The builder felt that sizing a ventilation system, assuming no natural infiltration, would result in excessively high air change rates in a house that was less than airtight. This would increase

energy costs to operate the house, that would negate any benefit from higher insulation levels and a high efficiency furnace. In addition, the incremental cost to airtighten the house and install a suitable HRV system would make the house unaffordable.

4.2.1 Airtightness Test - ON2

Actual airtightness test results are not available, as they were lost shortly after testing was completed. The airtightness tests did reveal an air change rate in excess of 5 acph at 50 Pa. Major leakage areas included: windows, joists electrical outlets, plumbing penetrations, and fireplace perimeter.

4.2.2 Ventilation System Air - ON2

Table 4.2 indicates that, the required, minimum, continous fresh air flow, based on the number of habitable rooms, is 55 L/s. The actual continuous exhaust rate was found to be 102 L/s. This exhaust rate did not change significantly when all the booster fans were turned on. In fact, air flow measurements in individual exhaust ducts revealed reverse air flows when some booster fans were not operating. Only 16 L/s of fresh air flow was measured at the passive vent, by the furnace. This flow did not change significantly with the operation of the exhaust fan or furnace. The flow appeared to be more directly influenced by wind speed and direction.

4.2.3 Distribution System Air Flows

Based on the required minimum fresh air flow of 55 L/s and the design of the air distribution system, theoretically, most of the rooms would not receive the minimum fresh air flow of 5 L/s as indicated in Table 4.2. Assuming perfect mixing of fresh air with recirculated air, although we are not sure where the fresh air is coming from, the actual flow measurements indicate that most of the rooms are receiving at least the minimum of 5 L/s. This is largely due to the high ventilation rate induced by the exhaust fan. Figure 4.2 illustrates schematically, the balance of air flows throughout the house.

TABLE 4.2
AIR FLOW BALANCE
HOUSE ID: ON 2
(L/s)

AIR CIRCULATION SYSTEM

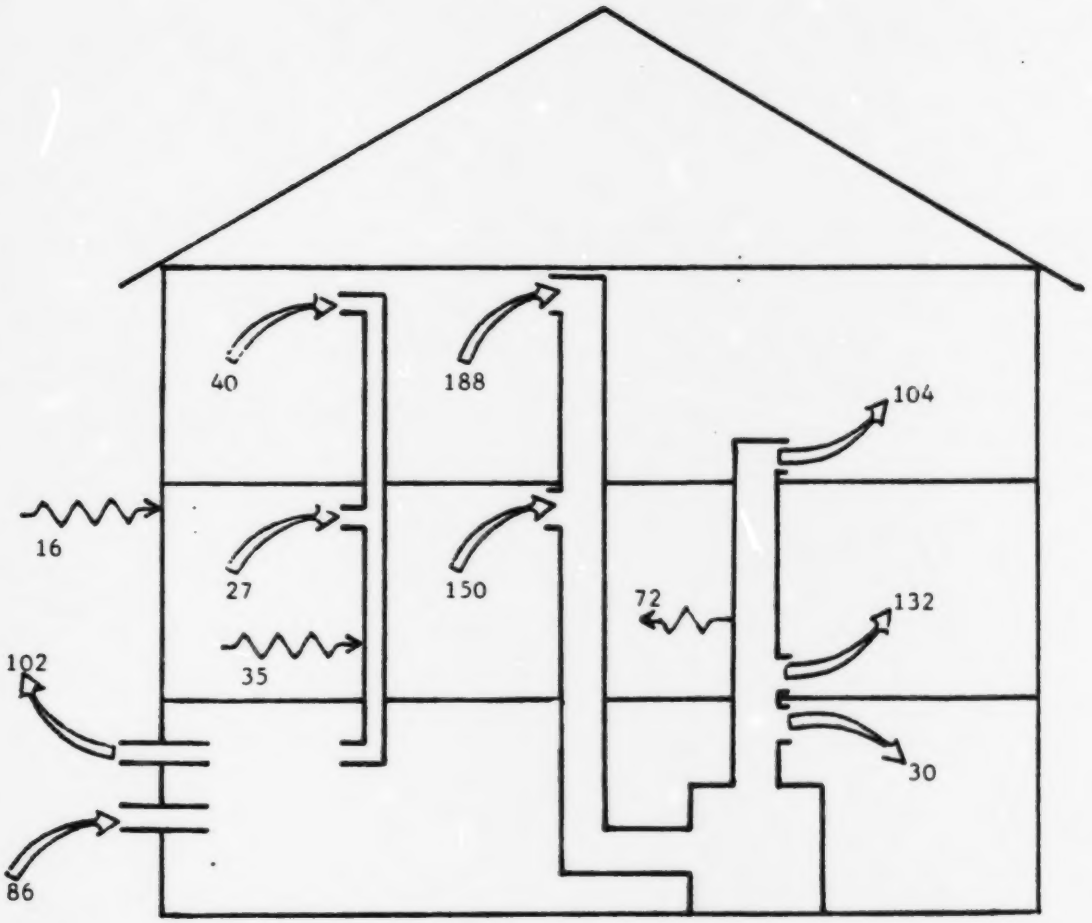
Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Grilles							
1 Living Room 1	3	25	5	30	20	14	6
2 Living Room 2	3	25	5	30	14	10	4
3 Hall	3	15	3	18	13	9	4
4 Bathroom	5	15	3	18	18	13	5
5 Dining Room	5	20	4	24	21	15	6
6 Kitchen	5	26	5	31	17	12	5
7 Side Hall	3	20	3	23	14	10	4
8 Powder Room	3	20	4	24	15	10	5
9 Rec Room	5	14	3	17	14	11	4
10 Basement	5	23	4	27	16	11	5
11 Bathroom 2	5	25	5	30	14	10	4
12 M. Bedroom 1	3	13	2	15	17	12	5
13 M. Bedroom 2	3	13	2	15	20	14	6
14 Bedroom 2	5	21	4	25	19	13	6
15 Bedroom 3	5	21	4	25	20	14	6
16 Bathroom 1	5	8	2	10	14	10	4
17 Duct Leakage(11)	0	0	0	0	72	50	22
Total Supply	55	307	55	362	335	234	101
Return Grilles							
R1 Return				121	150		
R2 Return				121	136		
R3 Return				120	52		
Duct Leakage(11)				0	0 (9)		
Total Return				362	338		
VENTILATION SYSTEM							
Exhaust				55	102		
Intake				55	16		
House Leakage(11)					86 (9)		
Total Outside Air				55	102 (10)		

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using HRAI's RSD Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.
10 Total outside air is based on greater of measured exhaust or intake.
11 Duct and House leakage account for differences between supply and return or exhaust and intake measurements.

FIGURE 4.2

AIR FLOW BALANCE

HOUSE ID: ON 2



All Flows in L/s

4.3 House ON3 - Test Results

ON3 is a two storey house equipped with a central forced air electric furnace. The house is constructed to meet R2000 standards. Ventilation is provided by a heat recovery system capable of exchanging 104 L/s at high speed. Fresh air is drawn from outside, preheated in the heat exchanger and ducted directly into the return air plenum of the furnace. Exhaust air is drawn from the laundry room, kitchen and each of the bathrooms. These exhausts are ducted to the HRV and used to preheat incoming fresh air. The exhaust fan operates normally at low speed. High speed is engaged automatically by dehumidstats in the laundry room and kitchen, or by manual switches in the bathrooms. There is a fireplace in the house which is equipped with a passive vent for combustion air supply.

4.3.1 Airtightness Tests - ON3

The measured equivalent leakage area (ELA) for this house, with ventilation openings unsealed, was 0.028 m^2 and air change rate at 50 Pa was 1.02 acph. There was very little change in airtightness when the ventilation openings were sealed. A significant increase in ELA and AC @ 50 Pa was observed when air tightness tests were conducted with the ventilation system running. ELA's increased to about 0.04 m^2 and the air change rate at 50 Pa increased to 1.2. There was no significant difference between operation of the ventilation system at low or high speed. This would suggest an imbalance in the intake and exhaust flows.

4.3.2 Ventilation System Air Flows - ON3

Table 4.3 specifies a minimum required ventilation air flow of 55 L/s, based on the number of habitable rooms.

Measurements of air flows on the HRV show an intake flow of 126 L/s. This is more than double the minimum required. It is also more than double the exhaust air flow rate. This confirms the findings of the air tightness tests, and indicates that the HRV is pressurizing the house, hence the higher ELA.

4.3.3 Distribution System Air Flows - ON3

Air flow calculations, based on the distribution system design, indicate that most rooms will receive the minimum fresh air flow of 5 L/s, assuming good air mixing in the return air plenum. Bedroom 2 was found to have no measurable flow of air. Total supply air was found to be 60% of that estimated from the designs. Figure 4.3 illustrates the balance of air flows through the house.

TABLE 4.3
AIR FLOW BALANCE
HOUSE ID: CH 3
(L/s)

AIR CIRCULATION SYSTEM

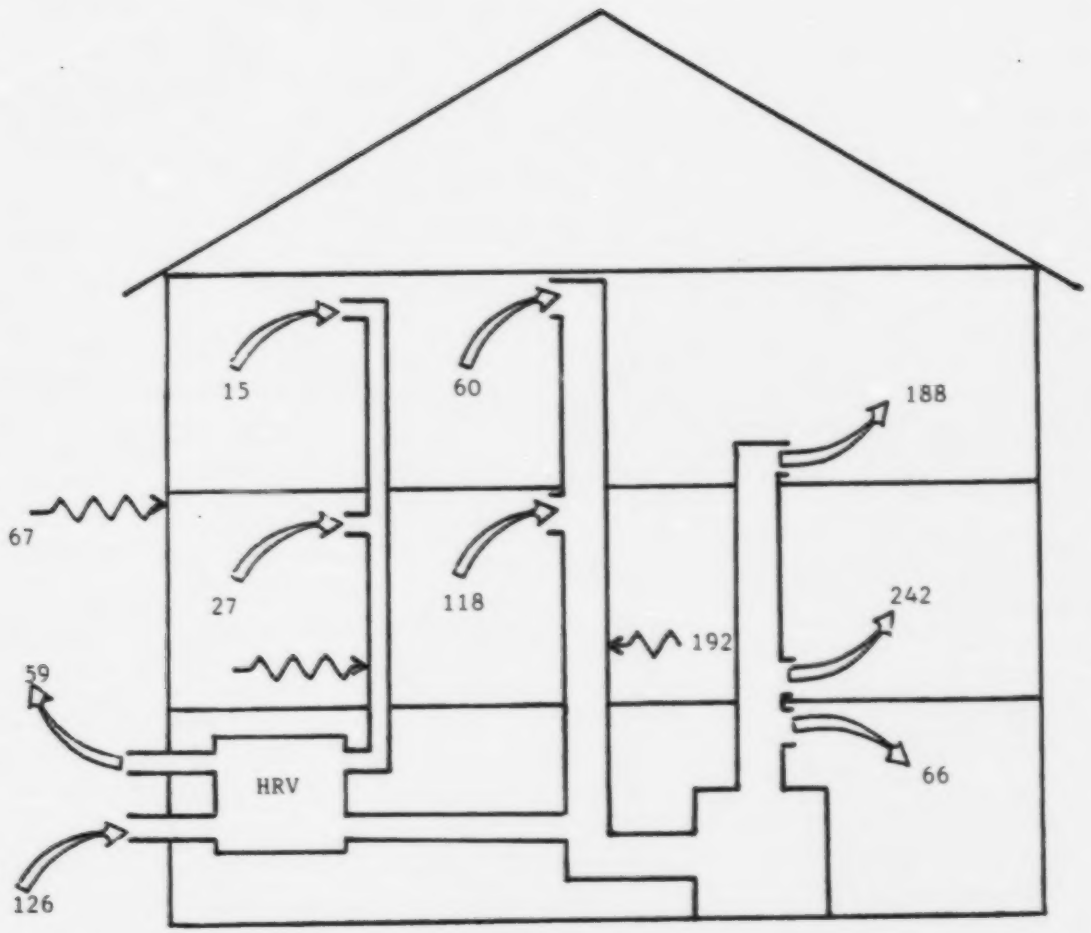
Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Grilles							
1 Master Bedroom	5	29	2	31	29	22	7
2 Master Bedroom	5	29	2	31	43	32	11
3 Master Bathroom	5	66	5	71	18	13	5
4 Hall Upstairs	0	36	3	39	22	16	6
5 Bedroom 2	5	34	3	37	0	0	0
6 Bathroom	5	34	3	37	10	7	3
7 Bedroom3	5	68	5	73	30	22	8
8 Bedroom 4	5	56	4	60	36	27	9
9 Kitchen	5	29	2	31	34	26	9
10 Kitchen	5	29	2	31	37	28	9
11 Laundry	0	43	1	55	8	1	2
12 Dining Room	5	30	2	34	17	13	4
13 Front Entrance	5	29	2	31	28	21	7
14 Living Room	5	74	5	79	70	52	18
15 Family Room	5	74	5	79	50	37	13
16 Basement	5	19	1	20	8	6	2
17 Basement	5	19	1	20	20	15	5
18 Basement	5	19	1	20	22	16	6
19 Basement	5	19	1	20	16	12	4
20 Duct Leakage(11)	0	0	0	0	0	0	0
Total Supply	55	743	55	796	496	370	126
Return Grilles							
R1 Return				398	118		
R2 Return				199	30		
R3 Return				199	30		
Outside Air				0	126		
Duct Leakage(11)				0	192 (8)		
Total Return				796	496		
VENTILATION SYSTEM							
Exhaust				55	59		
Intake				55	126		
House Leakage(11)					67 (9)		
Total Outside Air				55	126 (10)		

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using MH&L's RSD Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).

FIGURE 4.3

AIR FLOW BALANCE

HOUSE ID: ON 3



All Flows in L/s

4.4 House ON4 - Test Results

This house is a four level side split, heated with electric baseboard heaters. It has a heat recovery ventilation system which is nominally capable of exchanging 75 L/s at high speed. The ventilation system supplies fresh air into the basement, where it is circulated to the upstairs via a distribution or destratification fan, which takes air from the family room and delivers it to the upper level hallway. There is no direct distribution of air to individual rooms. Exhaust air is taken separately from the bathroom and the kitchen, and ducted through the heat exchanger. The rate of exhaust is controlled by a variable speed fan on the heat recovery unit. The exhaust fan runs continuously on low speed. High speed operation is controlled by manual timer in the bathroom, and a dehumidstat in the kitchen. The main problem with this design is the lack of air movement in the house, and the lack of fresh air directed to the bedrooms. Testing, using smoke pencils, revealed very little air movement into the bedrooms when doors were open, and almost none when doors were closed. Most of the air was moving through the hallways and stairwells, between the supply and return air grilles of the destratification system.

4.4.1 Airtightness Tests - ON4

The airtightness testing measured an ELA of 0.032 m^2 at 10 Pa, and an air change rate of 1.73 acph; with the HRV system unsealed and not operating. Sealing the ventilation openings reduced the ELA by 0.007 m^2 to 0.025m^2. Airtightness testing, with the ventilation system running at low speed, resulted in almost the same readings as the unsealed case, while tests with the HRV on high speed were closer to the sealed case. This house was built to meet R2000 standards, as these results would indicate.

4.4.2 Ventilation System Air Flows - ON4

Table 4.4 indicates that a minimum continuous air flow of 45 L/s is necessary to meet the suggested requirements of the proposed guidelines. The actual exhaust rate was found to be 15 L/s, and the actual fresh air intake was measured at 12 L/s; when the HRV was operating at low speed. The balance of 3 L/s is assumed to be entering the house through natural infiltration. At low speed operation, the HRV is supplying only one third of the required air flow. When operating on high speed, the HRV delivered only 36 L/s.

4.4.3 Distribution System Air Flows - ON4

As previously discussed, the only means of air distribution in the house is a destratification system, which draws air from the family room and blows it into a hallway on the upper floor. The use of conventional HRAI design procedures is meaningless, in this case. However, these design procedures provide a relative order of magnitude, for the amount of air to be circulated, in order to maintain adequate comfort levels. In this case, the results of the design procedures suggest an air circulation rate of 291 L/s. The actual measured air circulation rate of 13 L/s is approximately 4% of the recommended air flow. In addition, since the ventilation system is not directly coupled to the distribution system, there is no guarantee, that, what little fresh air is entering the house, is being distributed throughout. Based on the requirements of the proposed guidelines, there are serious deficiencies in the design and operation of the ventilation and air distribution systems in this house.

Figure 4.2 provides a schematic diagram of the overall air flow balance in the house.

TABLE 4.4
AIR FLOW BALANCE
HOUSE #: GH 4
(L/s)

AIR CIRCULATION SYSTEM

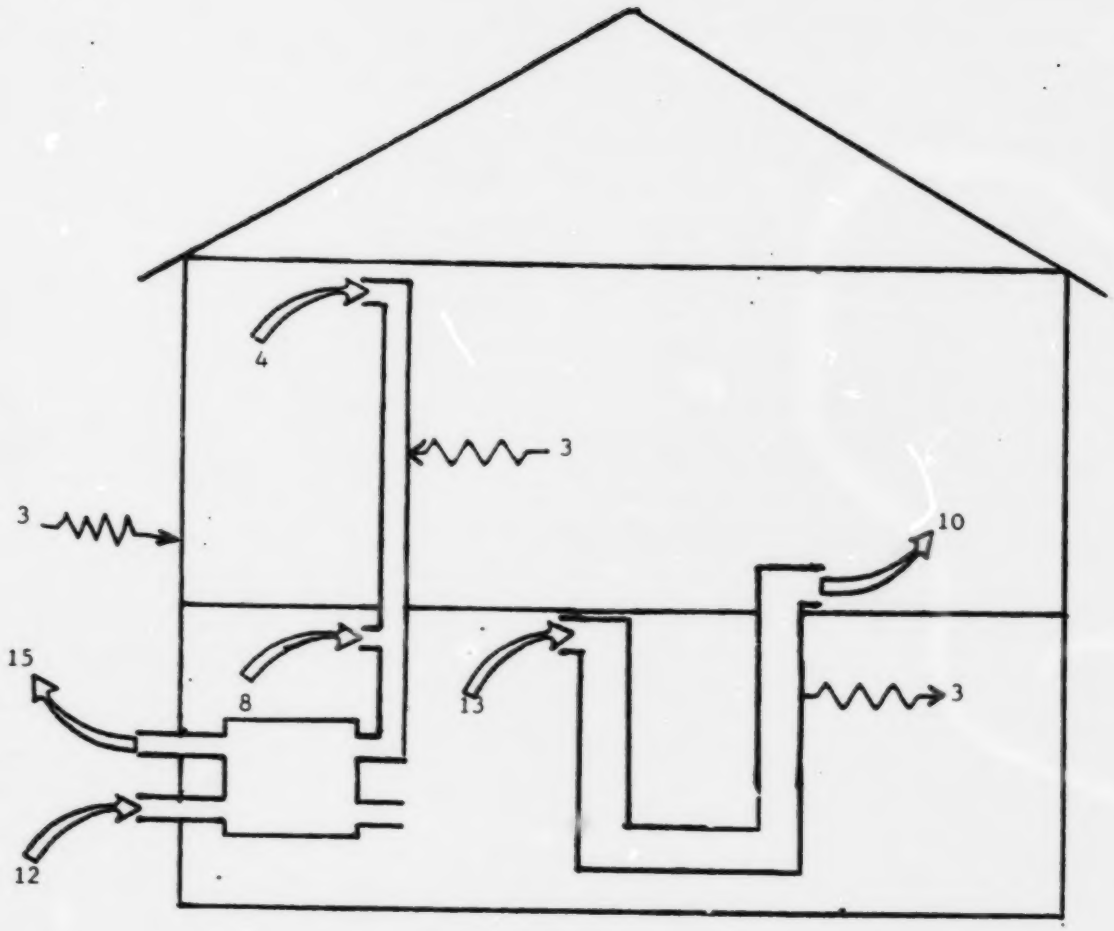
Location	Guidelines Req./Present (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Grilles							
1 Fam L Room	45	246	45	291	33	5	7
2 Master Bedroom	0	0	0	0	0	0	0
3 Bathroom	0	0	0	0	0	0	0
4 Hall Washline	0	0	0	0	0	0	0
5 Bedroom 2	0	0	0	0	0	0	0
6 Bedroom 3	0	0	0	0	0	0	0
7 Kitchen	0	0	0	0	0	0	0
8 Dining Room	0	0	0	0	0	0	0
9 Entrance	0	0	0	0	0	0	0
10 Living Room	0	0	0	0	0	0	0
11 Basement	0	0	0	0	0	0	0
12 Duct Leakage(11)	0	0	0	0	18	7	5
Total Supply	45	246	45	291	35	13	15
Return Grilles							
R1 Return				291	33		
Outside Air				51	15		
Duct Leakage(11)				0	0 (8)		
Total Return				351	28		
VENTILATION SYSTEM							
Exhaust				45	45		
Intake				45	42		
House Leakage(11)					3 (9)		
Total Outside Air				45	45 (10)		

Notes:
1 The Ventilation Guideline requires 5 L/s per habitable room.
2 Recirculated air = total flow less fresh air.
3 Fresh air=Total Fresh Air/Total Supply=Total Room Supply.
4 Total Room Supply calculated using MEA's HSE Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.
10 Total outside air is based on greater of measured exhaust or intake.
11 Duct and House leakage account for differences between supply and return or exhaust and intake measurements.

FIGURE 4.4

AIR FLOW BALANCE

HOUSE ID: ON 4



All Flows in L/s

4.5 House ON5 - Test Results

ON5 is a single storey house, which is built to R2000 standards. Ventilation is provided by a heat recovery system which draws exhaust air from the bathroom, kitchen and laundry room. The preheated fresh air is ducted to an upstairs hallway. It must travel approximately 8 metres through ductwork, after leaving the heat exchanger, before being "dumped" into the living space. The intention, here, is to further preheat the fresh air in the ductwork before introducing it into the living space. The HRV operates continuously on low speed. High speed operation is controlled automatically by dehumidistats in the bathroom and kitchen; and manually, by a switch in the laundry room. Air circulation and space heating are provided by a central electric forced air furnace.

4.5.1 Airtightness Tests - ON5

The equivalent leakage area (ELA) of this house was found to be 0.029 m^2, with the ventilation openings unsealed. This reduced to 0.022 m^2, when these openings were sealed. Further tests, with the heat recovery ventilator operating at low and medium speeds, did not vary significantly from the unsealed tests; while operation at high speed produced almost the same results as the sealed test. This would indicate that the intake and exhaust flows are fairly well balanced.

4.5.2 Ventilation System Air Flows - ON5

Table 4.5 shows a required minimum fresh air flow of 35 L/s. Actual fresh air flows measured, were in the order of 37-39 L/s, when the HRV was operating at low speed. High speed operation of the HRV produced flows in the range of 107-118 L/s. The degree of mixing between fresh air and inside air is uncertain, as there is no direct means to assure mixing.

4.5.3 Distribution System Air Flows - ON5

Table 4.5 also illustrates that, under design conditions, the living room is the only room which will receive the required minimum fresh air flow of 5 L/s, assuming perfect mixing of air flows. This is largely due to the amount of recirculated air which is distributed to the basement and hallways. Actual distribution air flows indicate that the basement is receiving the bulk of the distribution system air flow, hence the bulk of fresh air; again, assuming perfect mixing of these air streams. This may not be the case, since fresh air is introduced in the upper hallway. Figure 4.5 provides a graphical presentation of the air flow balance. It shows a fairly even flow between basement and the first floor. All of the return air is drawn from the first floor.

TABLE 4.E
AIR FLOW BALANCE
HOUSE 101 ON 5
(L/s)

AIR CIRCULATION SYSTEM

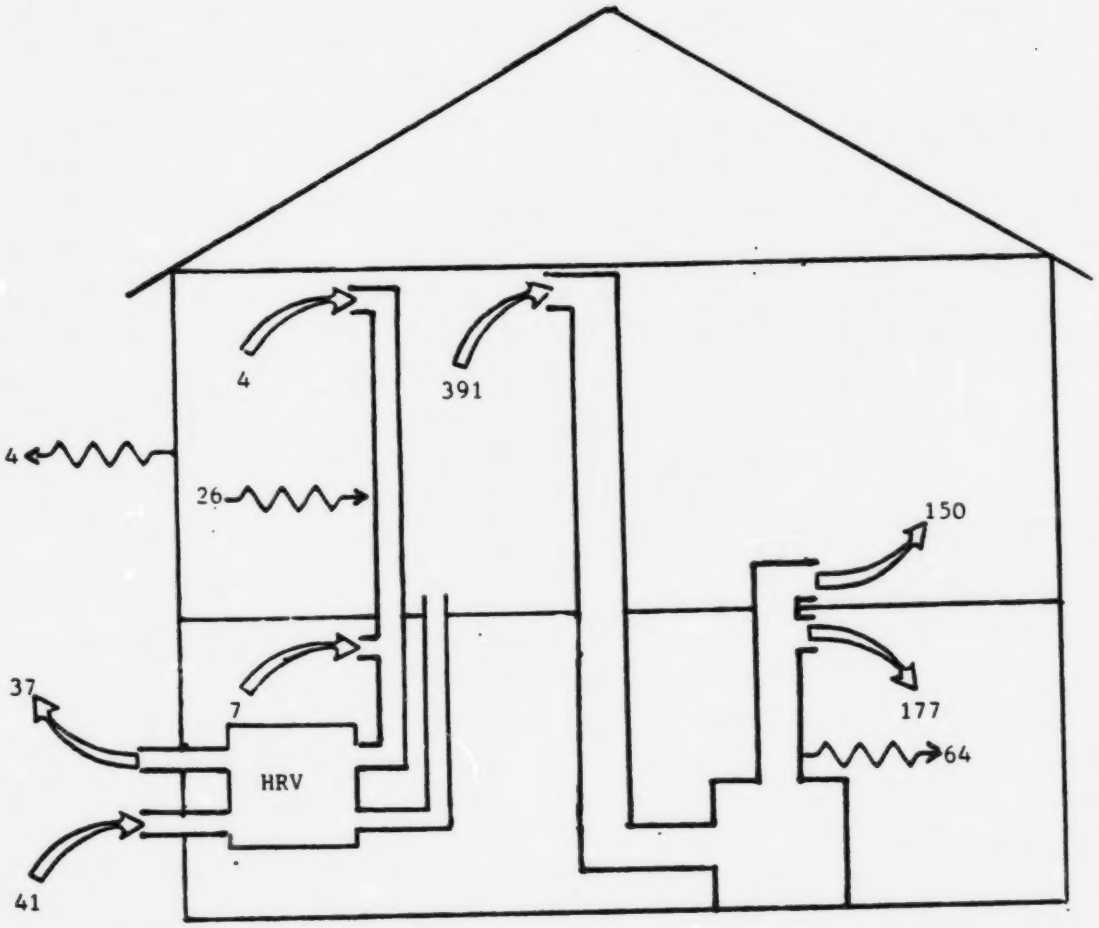
Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Grilles							
1 Bedroom 1	5	20	4	24	15	13	2
2 Bedroom 2	5	19	4	23	17	15	2
3 Bedroom 3	5	16	4	22	14	13	1
4 Bathroom	5	7	2	9	15	13	2
5 Hall	0	13	3	16	15	13	2
6 Dining Room	5	9	2	11	20	18	2
7 Living Room 1	3	9	2	11	19	17	2
8 Living Room 2	3	15	3	18	18	16	2
9 Hall	0	15	3	18	17	15	2
10 Basement	5	7	1	8	36	33	3
11 Basement	4	7	1	8	26	23	3
12 Basement	6	7	1	8	24	21	3
13 Basement	6	7	1	8	27	24	3
14 Basement	6	7	1	8	32	29	3
15 Basement	6	7	1	8	38	34	4
16 Duct Leakage(11)	0	0	0	0	64	57	7
Total Supply	35	165	35	200	391	350	41
Return Grilles							
R1 Return				100	194		
R2 Return				100	197		
Outside air				0	0		
Duct Leakage(11)				0	0 (8)		
Total Return				200	391		
VENTILATION SYSTEM							
Exhaust				35	37		
Intake				35	41		
House Leakage(11)					4 (9)		
Total Outside Air				35	41 (10)		

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using HSAI's RSD Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.
10 Total outside air is based on greater of measured exhaust or intake.
11 Duct and House leakage account for differences between supply and return or exhaust and intake measurements.

FIGURE 4.5

AIR FLOW BALANCE

HOUSE ID: ON 5



All Flows in L/s

4.6 House BC1 - Test Results

BC1 is a two storey house with a central, gas fired, forced air heating system. The house has a central heat recovery ventilation (HRV) system which has nominal air flow of 125 L/s. The supply air from the HRV is ducted directly into the return air plenum of the furnace. Exhaust air is taken from the kitchen, bathrooms and laundry room. The high speed operation of the HRV is controlled by a dehumidistat in the centre of the house, and by timer switches in the kitchen and washrooms. Low speed operation is adjusted in the laundry room, where the HRV hangs above the washer and dryer. The HRV also draws exhaust from the laundry room; however, this is controlled by a manual damper, which is to be opened only when the room is in use.

4.6.1 Airtightness Tests - BC1

BC1 was found to be relatively airtight, with an equivalent leakage area of 0.022 m^2, and 1.02 air changes per hour at 50 Pa. Chimney backdrafting tests were conducted at the same time as airtightness tests. These tests revealed that the furnace backdrafted when on standby, when the house was depressurized to 2 pascals. There was operating spillage at 4 pascals, and the furnace failed to overcome backdrafting when fired at 4 pascals depressurization. The water heater backdrafted on standby at 2.5 pascals, and was unable to overcome backdraft conditions when fired at 4 pascals depressurization. This information is displayed graphically in Figure 4.6.1.

The operation of the dryer depressurized the house to 5.5 pascals. When the dryer and heat exchanger were operated simultaneously, the house was depressurized to 7 pascals. Both of these levels are higher than the points at which operating problems occur with the furnace and water heater.

4.6.2 Ventilation System Air Flows - BC1

Table 4.6 presents the calculated and measured air flow balance for this house. It shows that the minimum required fresh air flow is 55 L/s. On low speed operation, the HRV exhausted 3 L/s, and drew in 5 L/s of fresh air. This is less than 10% of the required air flow. On high speed operation, the exhaust flow was 33 L/s, and the intake flow was 23 L/s. This is still less than the minimum required flow.

4.6.3 Distribution System Air Flow - BC1

Measured distribution air flows were found to be about 30% lower than recommended levels. This, combined with the low fresh air ventilation rate, results in almost no flow of fresh air to habitable rooms. This is illustrated further in Figure 4.6.2.

TABLE 4.6
AIR FLOW BALANCE
HOUSE ID: BC 1
(L/s)

Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
AIR CIRCULATION SYSTEM							
Supply Grilles							
1 Dining Room	5	34	7	41	26	25	1
2 Kitchen	5	19	4	23	14	14	0
3 Fam L. Room	5	35	7	42	26	25	1
4 Bathroom	5	7	2	9	6	6	0
5 Side Entrance	0	16	4	20	12	12	0
6 Den	5	18	4	22	14	14	0
7 Living Room	5	27	6	33	22 *	22	0
8 Bedroom 1	5	21	5	26	16	16	0
9 Bathroom Upstairs	5	8	2	10	6	6	0
10 Bedroom 2	5	16	4	20	12 *	12	0
11 Bedroom 3	5	7	1	8	5	5	0
12 Basement	5	47	10	57	35	34	1
13 Duct Leakage(11)	0	0	0	0	0	0	0
Total Supply	55	256	55	311	194	189	5
Return Grilles							
R1 Return			100	123 *			
R2 Return			100	123 *			
Outside Air			0	5 *			
Duct Leakage(11)			0	346 (6)			
Total Return			200	194			
VENTILATION SYSTEM							
Exhaust			55	3 *			
Intake			55	5 *			
House Leakage(11)				2 (9)			
Total Outside Air			55	5 (10)			

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using MRAC's RSC Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.
10 Total Outside air is based on greater of measured exhaust or intake.
11 Duct and House leakage account for differences between supply and return or exhaust and intake measurements.
12 * denotes actual measurement. All other flows estimated based on actuals.

FIGURE 4.6.1
CHIMNEY BACKDRAFT TEST - BC1

T_o = 25°C
T_i = 23°C

A STANDBY BACKDRAFT B OPERATING SPILLAGE C OPERATING BACKDRAFT D FAILS WHEN FIRED

CHIMNEY H = 9m

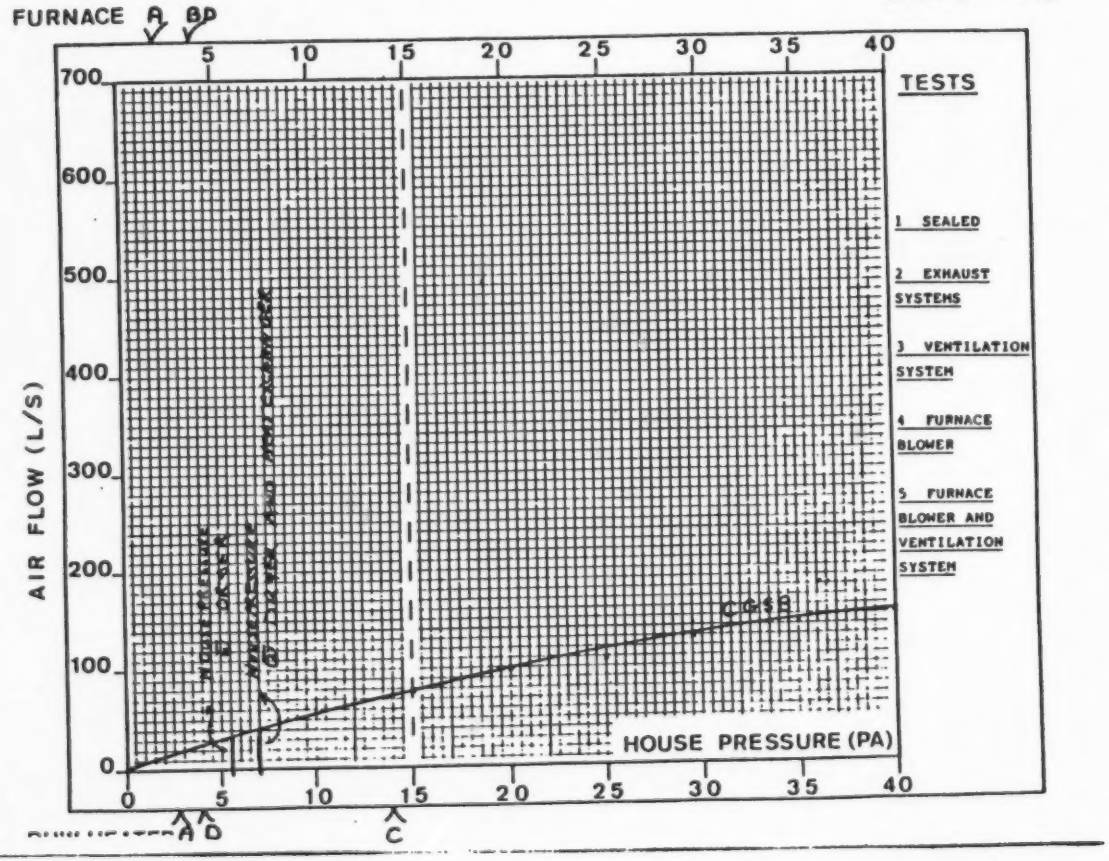
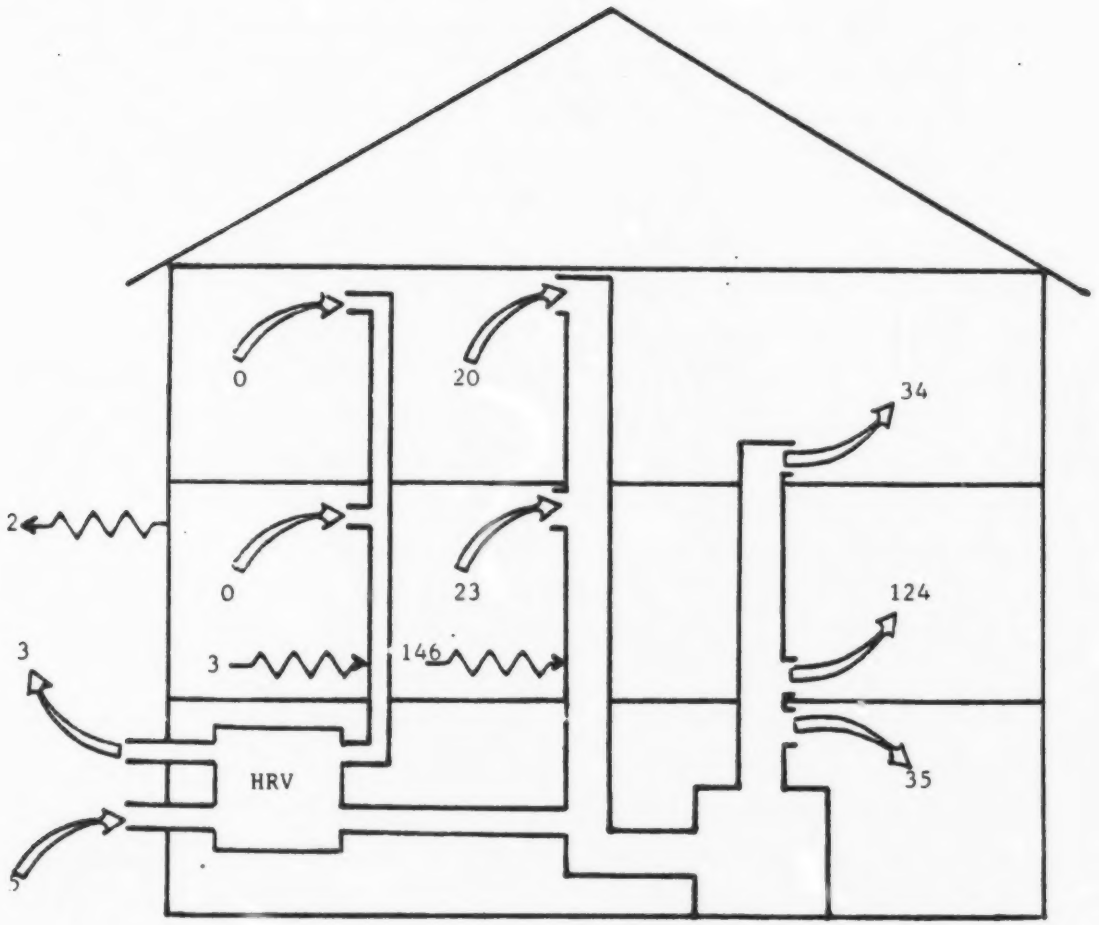


FIGURE 4.6.2

AIR FLOW BALANCE

HOUSE ID: BC 1



All Flows in L/s

4.7 House BC 2 - Test Results

BC2 is a two storey house with a forced air, gas fired furnace supplying heat to the main floor. The upper floors are heated with electric baseboards. The house is equipped with a central heat recovery ventilation system which draws exhaust air from the kitchen, 3 bathrooms and the laundry room. High speed operation is controlled by a dehumidstat. The continuous, low speed operation is adjustable by means of a variable speed control dial mounted on the unit. The HRV is rated at 125 L/s air flow. Fresh air, which is drawn through the HRV and preheated, is ducted into the return air plenum of the furnace.

As outlined in the proposed guideline, it is not recommended to operate a naturally aspirated furnace and water heater in conjunction with a controlled ventilation system, due to the possible risks of chimney backdrafting. For this reason, an induced draft fan was installed in the shared flue of the furnace and water heater. When space heating, or water heating, is demanded by respective thermostats; the induced draft fan is engaged. When adequate draft is established, a proving switch enables the burner of either the furnace or water heater. The induced draft fan has sufficient capacity to overcome any negative pressure which may exist. If it is unable to overcome the negative pressure, and hence establish adequate draft conditions, the proving switch will disable the burners, thereby eliminating the risk of backdrafting.

The house also has a gas fireplace, tightly constructed with no damper in the flue. The fireplace is equipped with a fixed, air inlet slot along the front face, at the bottom.

4.7.1 Airtightness Tests - BC2

This house is not as airtight as others in the study, with an equivalent leakage of 0.079 m^2, and 3.0 air changes per

hour at 50 Pa. The results of backdrafting tests are shown in Figure 4.7.1. This testing revealed that the exhaust system had very little effect on house pressure. In addition, the induced draft fan was found to spill badly for up to three minutes, when the furnace was fired against house pressures in the range of 6 to 10 Pa. The gas fireplace was found to backdraft completely at 4 pascals depressurization.

4.7.2 Ventilation System Air Flows - BC2

The required minimum fresh air flow, as indicated in Table 4.7, is 75 L/s. Actual measured air flows revealed an exhaust rate of 63 L/s, and an intake rate of 74 L/s. High speed operation of the HRV resulted in exhaust and intake flows of 97 L/s.

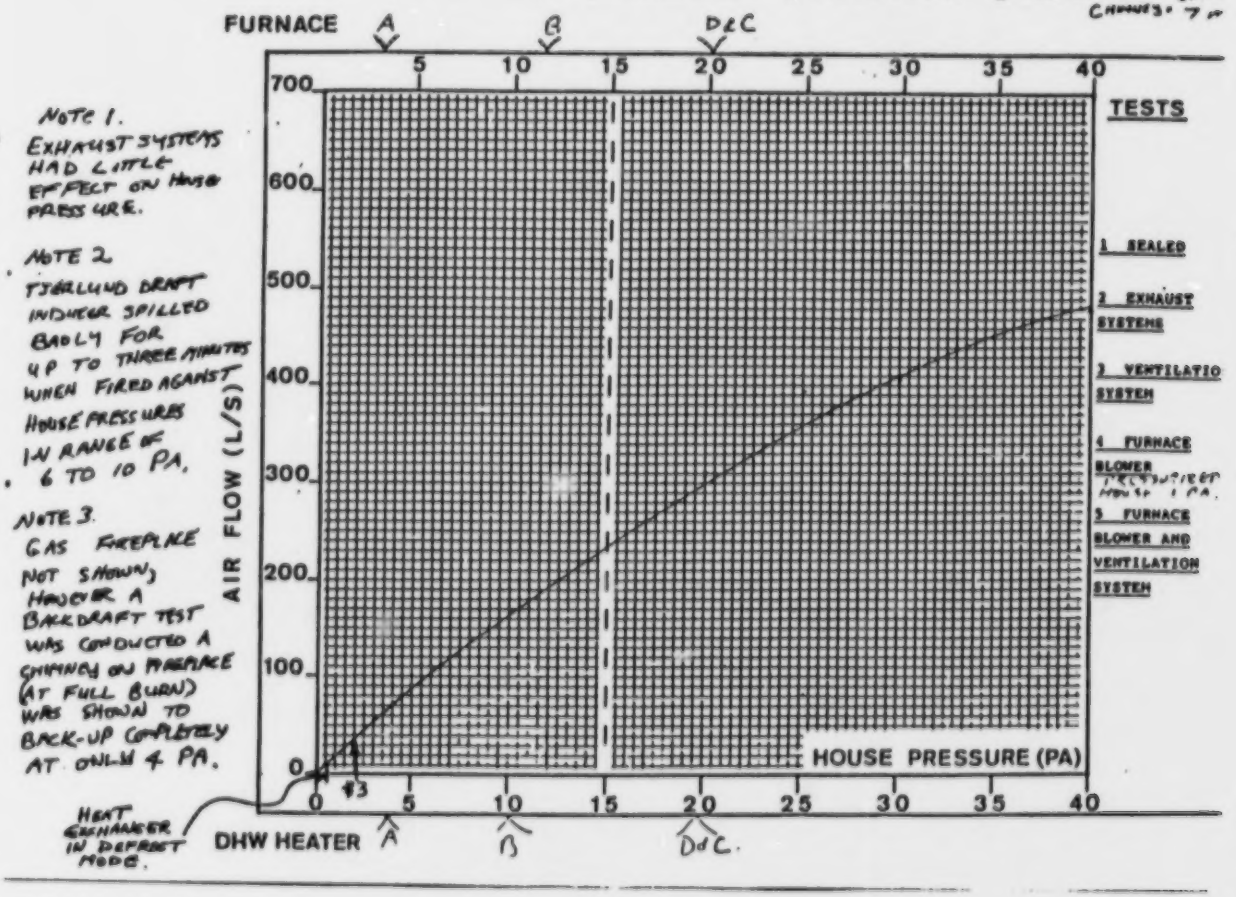
4.7.3 Distribution System Air Flows - BC2

As illustrated in table 4.7, and depicted in Figure 4.7.2, there is no controlled flow of air to the rooms on the upper floor. Since the rooms on this floor are heated with electric baseboard heaters, no air distribution was provided to these rooms. Although the house is receiving an adequate supply of fresh air, there is no way of insuring that this air is reaching the rooms upstairs.

FIGURE 4.6.1
CHIMNEY BACKDRAFT TEST - BC2

A STANDBY BACKDRAFT B OPERATING SPILLAGE C OPERATING BACKDRAFT D FAILS WHEN FIRED

To = 23
Ti = 22
CHIMNEY = 7 m



NOTE 1.
EXHAUST SYSTEMS HAD LITTLE EFFECT ON HOUSE PRESSURE.

NOTE 2
TJERLUND DRAFT INDUCER SPILLED BADLY FOR UP TO THREE MINUTES WHEN FIRED AGAINST HOUSE PRESSURES IN RANGE OF 6 TO 10 PA.

NOTE 3.
GAS FIREPLACE NOT SHOWN, HOWEVER A BACKDRAFT TEST WAS CONDUCTED A CHIMNEY ON FIREPLACE (AT FULL BURN) WAS SHOWN TO BACK-UP COMPLETELY AT ONLY 4 PA.

HEAT EXCHANGER IN DEFROST MODE.

TABLE 4.7
AIR FLOW BALANCE
HOUSE ID: BC 2
(L/s)

AIR CIRCULATION SYSTEM

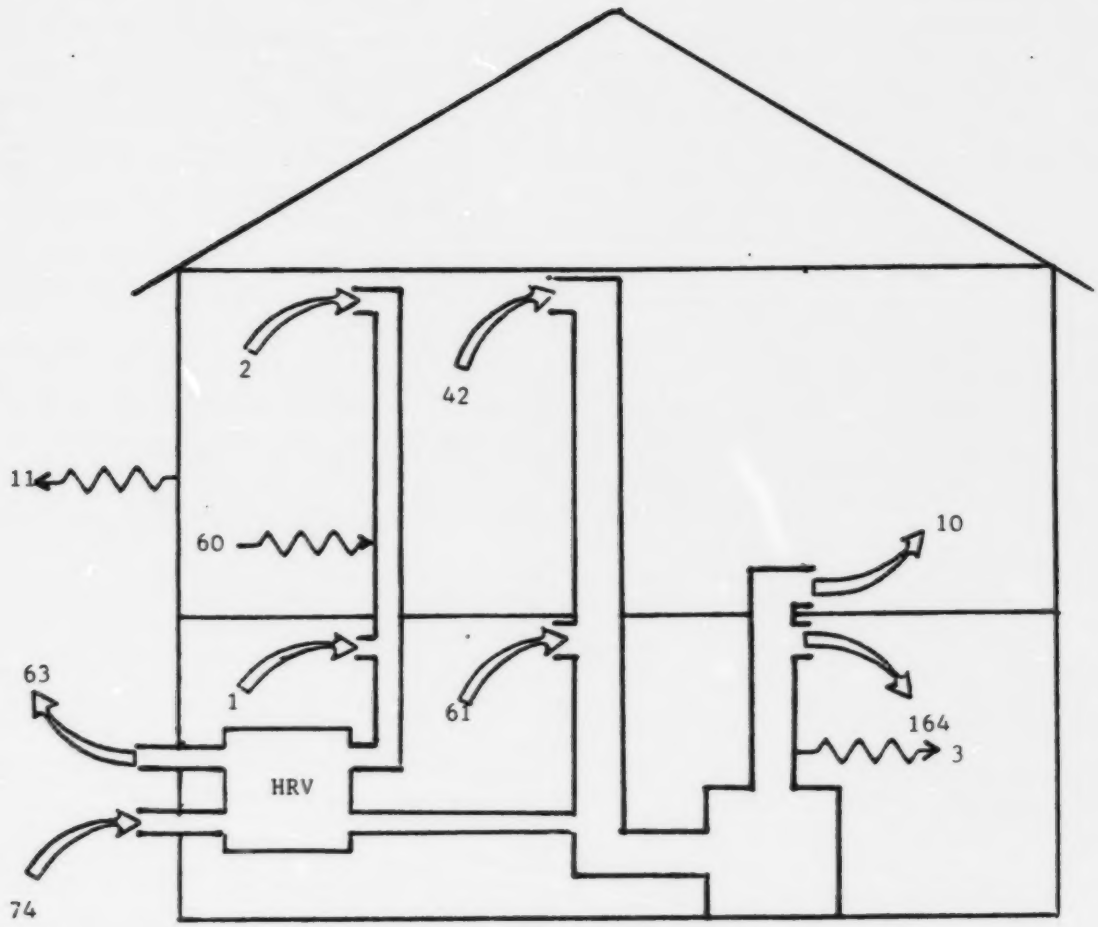
Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Outlet							
1 Kitchen	5	53	11	64	33	21	13
2 Pantry	5	22	5	27	14	8	6
3 Den/Family Room	5	21	4	25	13	8	5
4 Dining Room	5	25	5	30	15	9	6
5 Living Room	3	25	5	30	15	9	6
6 Living Room	3	25	5	30	15	9	6
7 Family Room	3	26	6	32	15	9	6
8 Family Room	3	26	6	32	26	9	7
9 Entrance	0	45	10	55	28	17	11
10 Master Bedroom	3	0	0	0	0	0	0
11 Master Bedroom	3	0	0	0	0	0	0
12 Office	5	0	0	0	0	0	0
13 Bedroom 2	5	0	0	0	0	0	0
14 Bathroom	5	14	3	17	17	10	7
15 Bedroom 3	5	0	0	0	0	0	0
16 Hall	0	0	0	0	0	0	0
17 Basement	5	0	0	0	0	0	0
18 Duct Leakage(11)	0	0	0	0	0	0	0
Total Supply	60	282	60	342	281	107	74
Return Grilles							
R1 Return				95	26		
R2 Return				95	35		
R3 Return				95	42		
Outside Air				0	74		
Duct Leakage(11)				0	4	(8)	
Total Return				285	181		
VENTILATION SYSTEM							
Exhaust				60	63		
Intake				60	74		
House Leakage(11)					11	(9)	
Total Outside Air				60	74	(10)	

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using HRAI's RSE Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.

FIGURE 4.7.2

AIR FLOW BALANCE

HOUSE ID: BC 2



All Flows in L/s

4.8 House BC3 - Test Results

BC3 is a two storey, semi-detached house contructed slab on grade. A zone heating system employs a gas fired, forced air furnace on the main floor, and electric radiant baseboards upstairs. Continuous exhaust is maintained by a two speed fan, mounted in the attic, exhausting through the gable. A plenum in the attic collects exhaust from ducts in the kitchen and the bathrooms. High speed operation is controlled by a dehumistat, or by manual switches in the bathrooms. Fresh air is supplied by means of a passive vent, which is ducted between the second floor joists, and connected into the return air plenum of the furnace. The inlet duct has a damper to allow reduction of the quantity of air entering the return system, to avoid excessive cooling of circulating air on colder days.

4.8.1 Airtightness Tests - BC3

The equivalent leakage area was found to be 0.097 m^2, with 6.2 air changes per hour at 50 Pa. This house is significantly more leaky than others in the study. The furnace was found to completely fail the chimney backdraft test at 7 pascals depressurization, as illustrated in Figure 4.8.1. The central exhaust and the clothes dryer created a 1.5 Pa pressure when operating together.

4.8.2 Ventilation System Air Flows - BC3

The minimum fresh air flow required for ventilation is estimated, in Table 4.8, to be 60 L/s. The ventilation system actually exhausted 18 L/s on low speed and 64 L/s on high speed. Air flows, in the intake vent, were found to be 4 L/s at both low speed and high speed operation of the exhaust fan.

4.8.3 Distribution System Air Flows - BC3

Since the second floor of this house has no air distribution system, the same problems as discussed for BC2 exist. However, in this case, the ventilation system is not providing an adequate flow of fresh air. This may not be a problem, in this case, as natural infiltration is probably significantly higher, due to the leaky construction of the house. Figure 4.8.2 illustrates the air flow distribution graphically.

FIGURE 4.8.1
CHIMNEY BACKDRAFT TEST - BC3

T_o = 16°C
T_i = 20°C

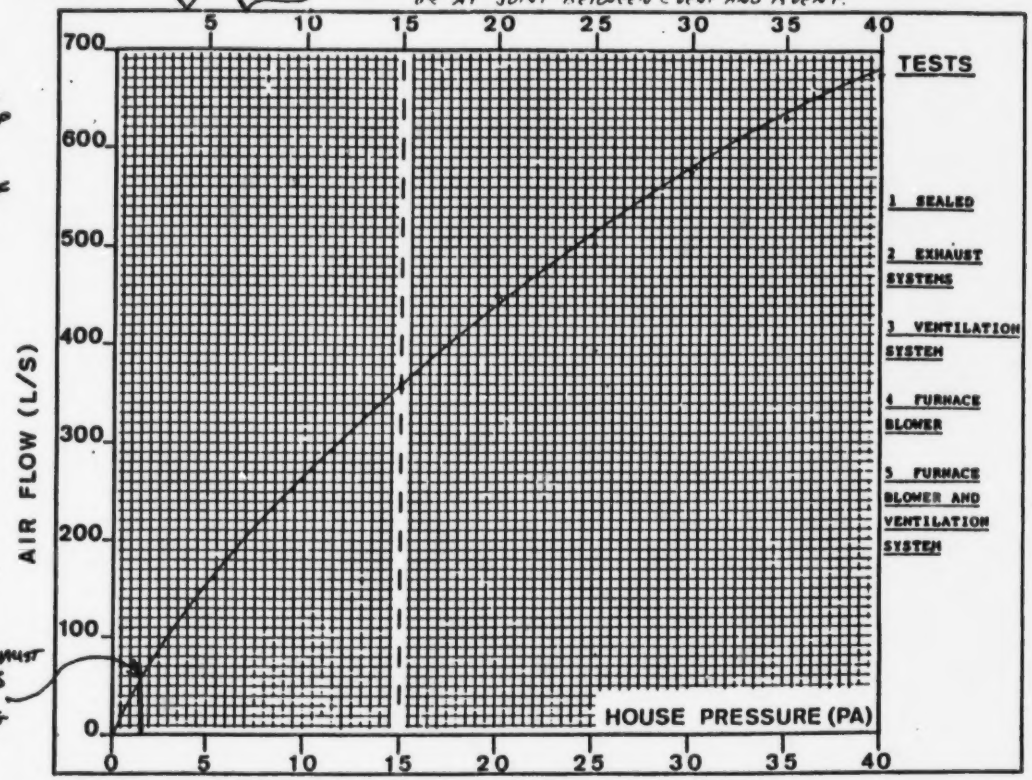
A STANDBY BACKDRAFT B OPERATING SPILLAGE C OPERATING BACKDRAFT D FAILS WHEN FIRED

FURNACE A * DBLC,

NOTE THAT FURNACE FLUE SPILLS AND BACKDRAFTS THROUGH DHW CONNECTION OR AT JOINT BETWEEN C VENT AND A VENT.

CHIMNEY = 7m

*REQUIRED 40 SECONDS TO REESTABLISH UP DRAFT WHEN EXPERIENCING BACKDRAFT OF 4 PASCALS.



DHW HEATER (NOT YET INSTALLED)

TABLE 4.9
AIR FLOW BALANCE
HOUSE ID: BC 3
(L/s)

AIR CIRCULATION SYSTEM

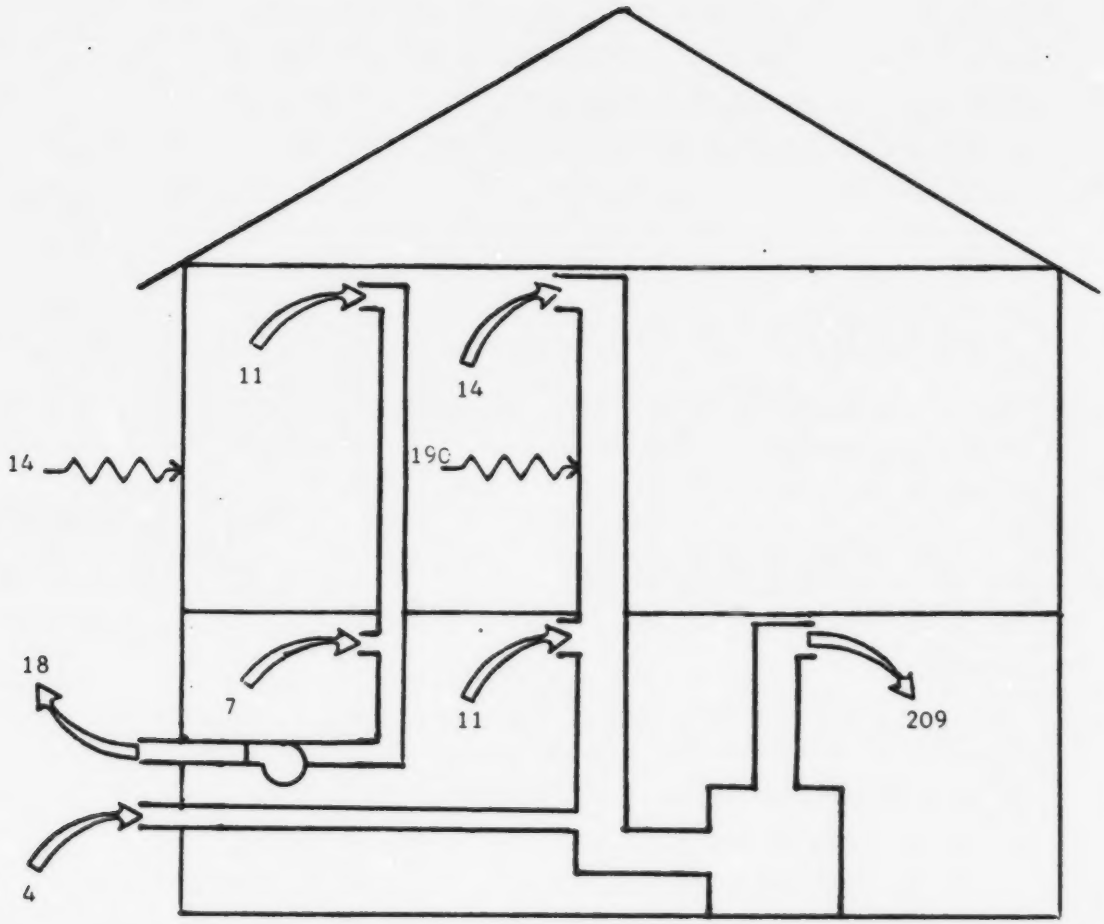
Location	Guidelines Requirement (1)	Calculated Recirc. (2)	Calculated Outside (3)	Calculated Total (4)	Measured Total (5)	Derived Recirc (6)	Derived Outside (7)
Supply Grilles							
1 Dining Room	5	19	6	25	25 ±	23	2
2 Living Room 1	3	19	6	25	31 ±	28	3
3 Kitchen	5	26	8	34	29 ±	27	2
4 Family Room	5	26	8	34	32 ±	29	3
5 Laundry Room	5	21	7	28	31	28	3
6 Entrance	0	21	7	28	32 ±	29	3
7 Living Room 2	3	23	7	30	29 ±	27	2
8 Master Bedroom	5	0	0	0	0	0	0
9 Master Bathroom	5	0	0	0	0	0	0
10 Bedroom 2	5	0	0	0	0	0	0
11 Bedroom 3	5	0	0	0	0	0	0
12 Bathroom	5	0	0	0	0	0	0
13 Bedroom 4	5	0	0	0	0	0	0
14 Duct Leakage(11)	0	0	0	0	0	0	0
Total Supply	50	154	50	204	209	181	19
Return Grilles							
R1 Return				102	11 ±		
R2 Return				102	14 ±		
Outside Air				0	18 ±		
Duct Leakage(11)				9	166 (8)		
Total Return				204	209		
VENTILATION SYSTEM							
Exhaust				50	19 ±		
Intake				50	4 ±		
House Leakage(11)					14 (9)		
Total Outside Air				50	18 (10)		

Notes:
1 The Ventilation Guidelines require 5 L/s per habitable room.
2 Recirculated air is total flow less fresh air.
3 Fresh air=(Total Fresh Air/Total Supply)*Total Room Supply.
4 Total Room Supply calculated using MNAIT's RSE Manual.
5 Measured air flows
6 Difference between 5 & 7
7 Outside air is based on total outside air pro-rated to each room in proportion to total measured air flow(5).
8 Difference between sum of measured return flows & sum of measured total.
9 Difference between intake and exhaust.
10 Total outside air is based on greater of measured exhaust or intake.
11 Duct and House leakage account for differences between supply and return or exhaust and intake measurements.

FIGURE 4.8.2

AIR FLOW BALANCE

HOUSE ID: BC 3



All Flows in L/s

4.9 Comparison of Field Test Results:

Table 4.9 shows a summary of air flow measurements for the installed ventilation systems. Also shown in this table, is the mininum air flow suggested by the guidelines for low and high speed operation of the ventilation systems. The difference between measured intake and exhaust flows are considered to be due to infiltration or exfiltration of air through the envelope of the house. In each case, the higher of the two air flows is used as a measure of the controlled ventilation rate of the house. The ventilation system, in five of the houses tested, came close to, or met the minimum fresh air flow requirements suggested by the guidelines. Of these, only three were able to meet the higher speed air flow requirements, suggested by the guidelines.

The following are observations concerning the houses in which the continuous ventilation was substantially less than the required.

The HRV in ON-4 is nominally capable of 75 L/s, yet at low velocity, the exhaust rate is 15 L/s, and the intake rate is 13 L/s; and at "high speed", the exhaust rate is 36 L/s and intake 33 L/s. According to house plans and ducting layout, duct runs are not long or complex. It appears the HRV is not operating up to its specifications.

In BC1, the HRV has nominal a flow rate of 125 L/s, yet the actual air flows are ridiculously low at the low setting; and only 22% of the HRV nominal capacity at high speed. The house is one of the tightest, yet there are no complaints of humidity and odour problems.

The intake and exhaust fans in BC3 are also performing below specification. In this case, however, the occupants have complained of odour problems.

Table 4.10 shows a summary of air flow measurements for the air distribution system in these houses. In general, except for ON5 and BC3, the measured flows are significatly lower than the calculated flows. It should be noted that the calculated flows are based on HRAI recommended design procedures as specified in their Residential System Design Manual. This does not imply that the individual builders used these design procedures to size ductwork and select equipment. These calculated flows are used here to provide a reference point only. The actual flows were measured at supply outlets or return inlets, and do not take into account any direct reading of total air flow.

As illustrated in the summary of air flows for individual houses, less than the suggested 5 L/s of fresh air is being delivered to each habitable room. The calculations and actual flow measurements reveal some fundamental problems with realizing this minimum requirement. Seven out of the eight builders used a central forced air system to deliver the fresh air throughout the house. This included distribution to habitable, as well as usually non-habitable rooms or areas such as hallways, entrances and laundry rooms. Therefore, if the ventilation system was sized to supply the minimum fresh air flow, based on habitable rooms, and this air was mixed with recirculated air; then the actual flow of fresh air to individual rooms was more dependent on the number and size of supply grilles. In addition, houses which used baseboard electric heating in part or all of the house, usually made no provision to supply any air to those rooms, whether the ventilation system was sized and operating appropriately, or not.

Figure 4.9 compares the air being delivered to each room with that designed for, on the basis of heat load calculations. It can be seen that there are marked differences between houses, with respect to the spread of mean values. House ON3, for example, shows a pattern that virtually circumscribes all the other points on plot. It is a wonder that this house does not display substantial temperature variations between rooms. By contrast, BC-3 has virtually all of the points within a -/+ 20% spread. These 20% lines are arbitrarily chosen to represent the sort of spread which might reasonably be expected in well designed and balanced systems.

Table 4.11 displays a frequency distribution of estimated outside air supply per room relative to the target of 5 L/s. House ON-2 comes quite close to achieving this goal; but does not perform well in terms of total air flow relative to target, as illustrated in Figure 4.9, and Table 4.11..

This disparity illustrates the inconsistency of having an absolute criteria of 5 L/s outside air; and a variable one, which is dependent on design heat loss.

With the spread of results, it is evident from the data collected, and the lack of negative reaction by the occupants, that one or more of the following would seem to apply.

1. The data is wrong.
2. People are not perceptive of air change rates.
3. The air change which occurs other than by influence of the mechanical ventilation system is significant.

Some improvements to the test procedures are required; however, the results obtained do provide a good indication of the level at which the ventilation systems are operating. The second and the third points provide little in the way of clues as to

which is the more significant. It appears to be an area in which further research may be required.

No attempt has been made to estimate the unintended air change rate, based on the airtightness measurements made. Though in the majority of the houses tested, this will be a modest contribution. In the houses which have a very low mechanical ventilation rate, the unintended ventilation probably constitutes a significant proportion of the total air change. The aspect of not making allowance for unintended ventilation is a justifiable criticism of the Ventilation Guide Lines.

TABLE 4.9
SUMMARY OF VENTILATION SYSTEM AIR FLOWS

Ventilation Rates (L/s)

House No.	Low Speed Required	Low Speed Measured	Low Speed Ratio	High Speed Required	High Speed Measured	High Speed Ratio
ON1	40	34	85%	80	39	49%
ON2	35	102	291%	110	102	93%
ON3	55	126	229%	110	126	114%
ON4	45	15	33%	90	36	40%
ON5	35	41	117%	70	118	169%
BC1	55	5	9%	110	33	30%
BC2	75	74	99%	150	97	65%
BC3	55	18	33%	110	64	58%
MEAN	50	52	112%	104	77	74%

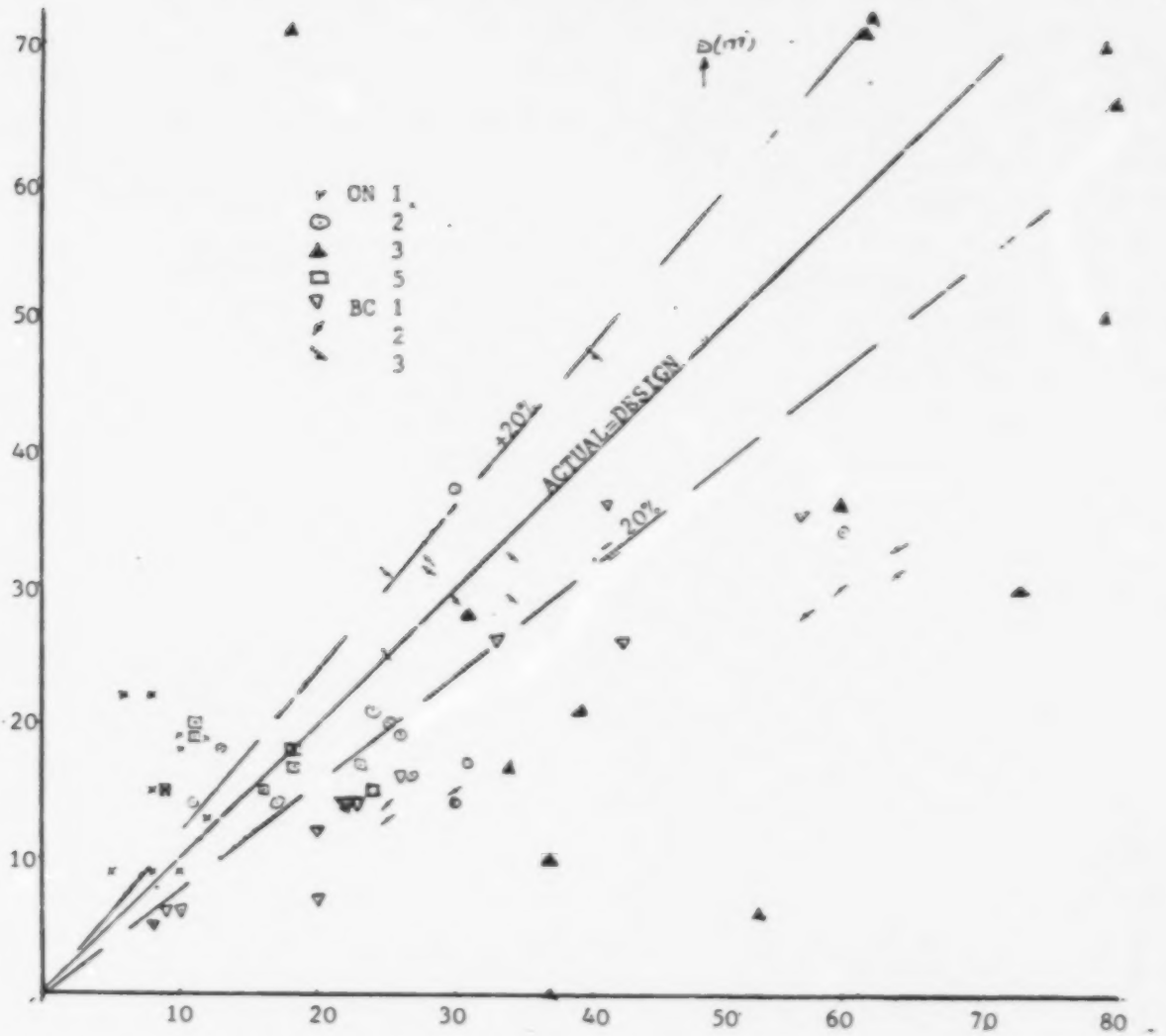
Table 4.10
AIR CIRCULATING SYSTEM FLOW MEASUREMENTS

House No.	Required Circulation Rate (L/s)	Measured Circulation Rate (L/s)	Measured as % Required
ON1	170	98	58%
ON2	362	338	93%
ON3	796	496	62%
ON4	291	13	4%
ON5	200	291	196%
BC1	311	194	62%
BC2	342	174	31%
BC3	204	209	102%

FIGURE 4.9

TOTAL AIR FLOW DELIVERED TO EACH ROOM

DESIGN VS ACTUAL



DESIGN FLOW

(L/S)

TABLE 4.11

FREQUENCY DISTRIBUTION

ESTIMATED OUTSIDE AIR PER ROOM

FREQUENCY AT SPECIFIED AIR FLOW

HOUSE	TARGET											
No.	0	1	2	3	4	5	6	7	8	9	10	10
ON1	-	-	2	7	2	-	-	-	-	-	-	-
On2	-	-	-	-	5	4	3	-	-	-	1	1
ON3	1	-	1	1	1	1	1	1	1			1
ON4	NO DUCTED AIR DISTRIBUTION SYSTEM											
ON5	-	1	7	-	1	-	-	-	-	-	-	-
BC1	8	3	-	-	-	-	-	-	-	-	-	-
BC2	-	-	-	-	1	1	2	-	-	-	-	4
BC3	-	-	3	4	-	-	-	-	-	-	-	-
TOTAL	8	4	13	11	10	6	6	1	1	-	1	6

NOTES:

1. Air delivered to basements excluded
2. Where there are two outlest per room, the aggregate air flow is used.

5.0 HOMEOWNER QUESTIONAIRE

In order to obtain the views of the eight homeowners involved in this study, concerning the heating and ventilation system, a questionaire was sent to them, followed by a telephone call. Since the homeowners operate these systems, their perception of performance is also important. The homeowner's acceptance is necessary to ensure the continued effectiveness of these systems in the future.

Results of the questionaire can be found in Appendix C, Design Data & Test Results. A summary of the questionaire responses is shown in Table 5.1. Note house ON1 is not included in the questionaire because the house is still vacant, and the residents of ON4 could not be reached.

The majority of the homeowners have lived in their houses between 6-12 months, and have experienced one winter with the heating and ventilating systems operating. In general, the houses are comfortable, except that they are slightly too humid. This may be due to the initial drying of construction materials in the house, and this condition may disappear by the following winter.

The ventilating systems seem to be operating properly and no lingering odours are present. However, the noise level, due to the ventilating system, in most houses, is higher than expected, and sometimes considered bothersome.

In some cases, the homeowners do not operate the ventilating equipment on a continuous basis. When questioned about this, the homeowners indicated that the operation of the ventilation system had not been explained to them by the builder. Overall,

most homeowners are happy with their system. Some changes, or improvements, which the homeowners would like to see include:

1. Reduced noise levels,
2. Better air distribution and balancing,
3. Improved layout of ducting for HRV equipment.

It is interesting to note (from table 5.1) that perception of high humidity was indicated for houses ON3, ON5, and BC2; all of which, according to the measurements taken, were sufficiently well ventilated houses. The only match between consumer observation and ventilation rate is with BC 3. Complaints of odour reflect the low ventilation rate of the house; but it is relatively leaky house, and the occupants also noted cold drafts.

Tale 5.1

SUMMARY OF RESPONSES TO HOMEOWNER QUESTIONAIRE

House No.	Occupancy (months)	No. of Occupants	Temp.	Humidity	Drafts	Noise	Odours	Vent System Operation	Overall Satisfaction 1-5
ON1	0	0	0	0	0	0	0	0	0
ON2	12	3	OK	OK	No	Yes	No	Manual	5
ON3	6-12	4	OK	High	No	Yes	No	Manual	5
ON4	6-12								
ON5	6-12	4	OK	High	No	Yes	No	Continuous	5
BC1	6-12	4	OK	OK	Yes	No	No	Continuous	5
BC2	6-12	6	OK	High	Yes	Yes	Yes	Manual	3
BC3	6-12	4	Cool	OK	Yes	Yes	Yes	Manual	3

6.0 CONCLUSIONS

Based on the results of this field evaluation of the draft CHBA Guidelines for the Design and Installation of Residential Controlled Ventilation Systems, the following conclusions are made.

6.1

The guidelines were found to be far too complex for the builders to fully comprehend. The technical scope of the guidelines was beyond the understanding of the "typical" builder, and did not provide the builders with the necessary "tools" to ensure that a proper ventilation system was designed and installed. In addition, the heating and ventilating contractors employed by the builders were reluctant to abandon traditional design and construction practices; and unwilling, or unable, to comprehend the concepts presented in the Guidelines.

6.2

The Guidelines do not adequately address issues such as:

- sizing and selection of ventilation equipment,
- mixing and distribution of fresh air using conventional forced air heating systems,
- design practices with respect to combustion appliances,
- allowances for natural infiltration.

6.3

There is a lack of supporting documents such as designers manuals and installers manuals.

6.4

There are problems with the availability and performance of equipment required to build some of the systems suggested in the guidelines. This is especially evident for ventilation systems in houses with combustion appliances. At the time of this study, induced draft water heaters were not commercially available. Induced draft fans required special permits for installation, and are not readily available. Commerically available Heat Recovery Ventilators have limitations on their ventilation capacities. Automatic vents for combustion air supply are also not readily available.

6.5

The test procedures used in this study were inadequate to produce a complete air flow balance for the house. The major areas of deficiency were in determining duct leakage and natural infiltration rates.